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(54) **Power assisted steering gear assembly**

(57) A power assisted steering gear assembly has a rack bar 1 which is biased at 7 through a bearing surface 9*a* for its teeth to engage a straight toothed pinion 5. The rack teeth 4 vary in pitch on a pitch line 13 with the teeth in a central region 10 having a pitch which is less than the teeth in each end region 11. The pitch line 13 and bearing surface 9*a* are profiled with respect to each other so that the biasing force exerted by 7 is greater when the pinion engages with the rack teeth 11 of larger pitch than when the pinion engages with the rack teeth 10 of smaller pitch. The variation in biasing force may be achieved by smoothly recessing the bearing surface 9*a* over the longitudinal extent of the rack or by varying the effective height of the rack teeth to vary the pitch line of the rack relative to the bearing surface 9*a*.

Fig.1.

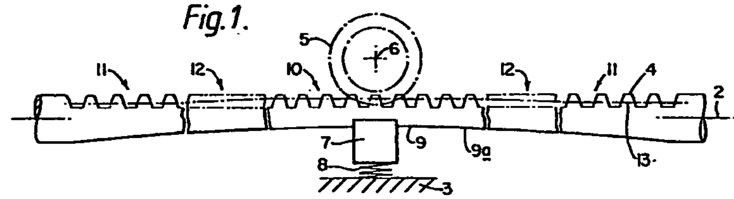
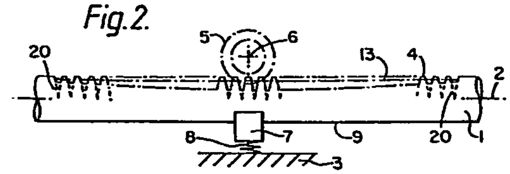


Fig.2.



The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

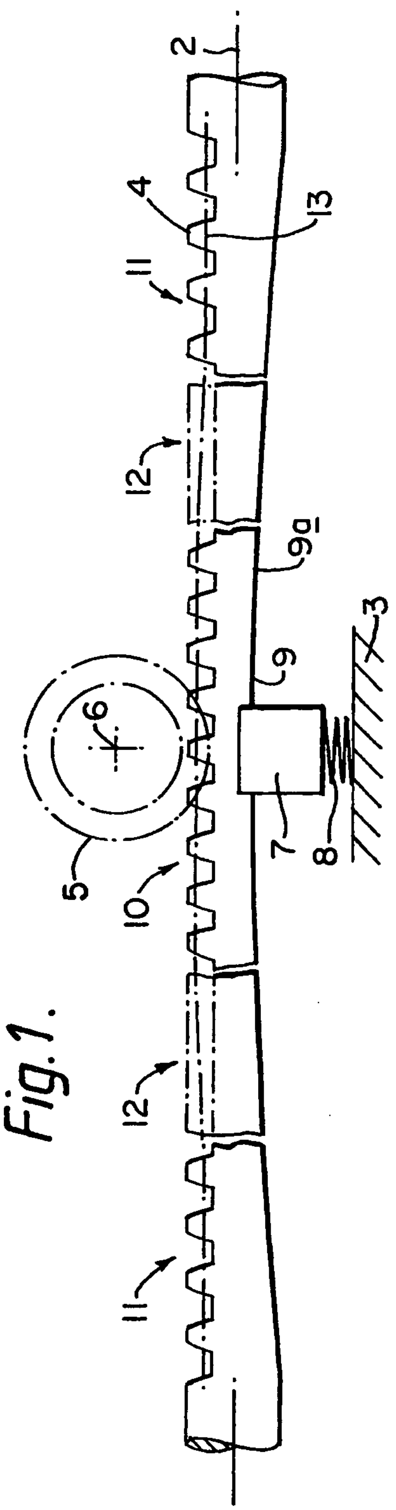
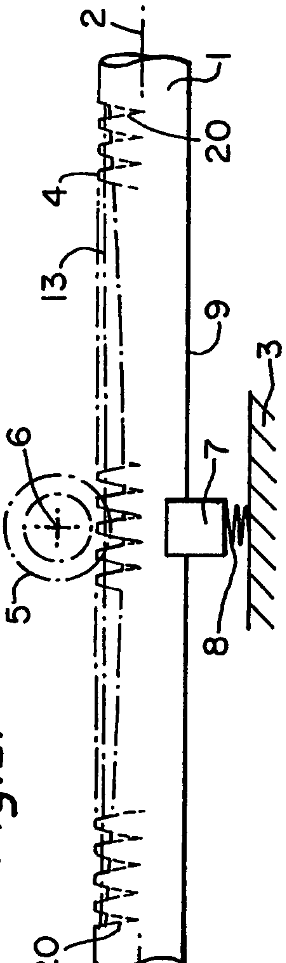


Fig.2.



SPECIFICATION

A power assisted steering gear ass mbly

Technical field and background art

This invention relates to a power assisted steering gear assembly and particularly concerns such an assembly having a rack bar a rack on which is engaged by a rotatably mounted pinion so that rotation of the pinion in response to a steering input results in displacement of the rack bar to provide a steering output. With such an assembly it is conventional to provide a servo motor associated with the steering output and control means which is responsive to the steering input and controls operation of the servo motor to provide power assistance for the steering output. It has also been proposed to provide such so-called rack and pinion steering with a gear ratio which varies during displacement of the rack bar as a result of the driving engagement between the pinion and rack teeth, this being achieved by the rack teeth being formed with a pitch which varies with respect to the pinion teeth (as disclosed, for example in U.K. Specification No. 977,434 and U.K. Specification No. 1,356,172). With such variable ratio gears the change in effective pitch of the rack is arranged to be symmetrical about the centre of the operational length of the rack. When the gear is intended for use with power assistance it is usual for a central tooth region of the rack to have an effective pitch which is less than the pitch of the teeth at each end region of the rack so that the maximum mechanical advantage (and thereby the minimum velocity ratio between the pinion and the rack) is provided in the central region of the rack length. A reason for this is to relate the displacement of the rack to the sensitivity which is attributable to the control means for the servo motor (particularly where the control means is in the form of an hydraulic valve) so that the servo motor will be operated with a relatively small displacement of the rack bar from its central condition. Power assisted steering systems as above described and incorporating helically toothed pinions are increasingly being applied to motor vehicles. However, with a helical pinion and variable ratio rack it is necessary for the rack teeth to have a varying and non-uniform profile over their lateral extent as discussed in U.K. Specification No. 1,356,172; as a consequence the rack cannot be formed by conventional techniques such as broaching and the techniques which are usually adopted, such as forging or spark erosion, render the rack bars expensive items to manufacture. It is recognised that the manufacture of variable ratio rack teeth for use with a straight toothed (sometimes called a "spur") pinion as discussed in U.K. Specification No. 977,434 can be achieved using conventional broaching techniques and consequently such racks are far less expensive components than the variable ratio rack components f r use with h lical pinions. However, a problem with variable rati racks for spur-type pinions is that th ngagement between the pinion and rack teeth tends t be less firm than with variable ratio t eth for helical pini ns in a region of relatively large pitch betwe n the rack teeth - this region of less firm engagement is a possible source of vibrati n and nois betwe n the rack and pinion. Consequently variable ratio racks for us with helical pinions and for us with spur or straight toothed pinions as hitherto proposed have disadvantages in that the former is considered expensive for manufacture and the latter as possibly developing noise and loose engagement between the teeth and it is an object of the present invention to provide a rack and pinion type power assisted steering gear assembly which alleviates the aforementioned disadvantages.

Statement of invention and advantages

According to the present invention there is provided a power assisted steering gear assembly comprising a rack bar having a longitudinal axis along which it is displaceable in the housing; a rack on the rack bar, the crowns for the teeth of which are substantially coplanar and parallel to the longitudinal axis; a straight toothed pinion rotatably mounted in the housing with its teeth engaging the rack, said pinion being rotatable in response to a steering input to effect in displacement of the rack bar and provide a steering output; servo motor means associated with said steering output; control means responsive to said steering input and controlling said servo motor means so that the latter provides power assistance for the steering output; support means mounted in the housing oppositely to the position of engagement between the rack and pinion, said support means engaging a smooth bearing surface on the side of the rack bar remote from the rack to resiliently bias the rack into engagement with the pinion; said rack having teeth which, with respect to the pinion teeth, vary in pitch along a pitch line of the rack whereby the rack and pinion provide a gear ratio that varies during said displacement of the rack bar, the rack having a central tooth region the pitch of the teeth in which is less than the pitch of teeth in each end region of the rack, and wherein said pitch line and bearing surface are profiled with respect to each other over the longitudinal extent of the rack so that the biasing force exerted by the support means on the bearing surface to urge the rack into engagement with the pinion is greater when the pinion engages with the rack teeth of relatively larger pitch than it is when the pinion engages with the rack teeth of relatively smaller pitch.

The variable ratio rack teeth may be formed to provide a continuous and smooth ratio change over the whole length of the rack so that the pitch of the rack teeth progressively increases from the centre, mid-length position of the rack to each end thereof.

Alternatively the rack may have a central region of relatively small constant pitch teeth and end regions of relative large constant pitch teeth with varying ratio (transition) teeth between those regions. It is also possibl for the rack t have part lengths betw en the regions in which th teeth ar f varying pitch within which part lengths th teeth ar of constant pitch. With such possible variations in the form of rack teeth to provide the varying ratio as required, it is envisaged by the present invention that the pitch line and bearing surface will be profiled with respect to each other so that the

biasing force exerted by the support means will progressively and smoothly increase as the pinion moves int engagement with teeth of increasing pitch so that firm engagem nt is provided between those teeth to alleviate noise and a possible source of vibration or rattle within the gear.

The relative variation in profile between the bearing surface and pitch line of the rack may be achieved by varying the effective height of the rack teeth relative to the bearing surface which latter may be substantially straight and parallel to the longitudinal axis of the rack bar. This variation in height can be achieved whilst maintaining the crowns of the rack teeth substantially coplanar by appropriately forming the individual rack teeth so that the appropriate variation in profile of the pitch line is provided ot cause lateral displacement of the support means against its biasing and thereby the required increase in biasing force as the pinion moves into engagement with larger pitch rack teeth. Alternatively (or in addition) a required variation in biasing force exerted by the support means can be achieved by appropriately profiling the bearing surface with respect to the rack teeth (or more particularly with respect to the pitch line) so that the bearing surface is other than straight and parallel to the axis of the rack bar. With this in mind the bearing surface is preferably recessed over its longitudinal extent so that the support means will be displaced laterally away from the axis of rotation of the pinion as the rack moves longitudinally into a position where its larger pitch teeth engage with the pinion (and the resilient biasing provided by the support means is appropriately increased). This latter profiling of the bearing surface may simply be effected during manufacture of the rack bar by an appropriate honing or grinding process.

It is envisaged that in applying the present invention to a steering assembly for a conventionally sized motor vehicle an appropriate variation in biasing force will be achieved with a lateral displacement of the support means which may be indiscernible to the eye, for example such displacement being in the order of 0.003 to 0.005 inches (0.076 to 0.127 millimetres); this displacement will be effected smoothly from the centre of the rack to each end thereof.

The appropriate biasing force exerted by the support means may be set-up with the pinion engaging the rack in its mid-length position so that there is a conventionally accepted feel or engagement between the rack and pinion, although the firmness between the rack and pinion will increase as the rack is driven towards one or other-of its ends this should be imperceptible to the driver.

A particular advantage of the present invention is that since the rack teeth are intended to engage with a straight toothed pinion, the rack teeth will also be straight (although some or all of them will have varying profiles t their flanks) and accordingly th rack can be produced by conventional br aching techniques.

Where, for xample, the bearing surface is substantially straight and parallel to the axis of th rack bar and the height of th pitch line with respect to the b aring suface is varied to pr vid the r quired biasing, the aforem ntioned br aching techniqu f r determining the final form of rack te th can be applied with advantage. F r example, the central tooth broaching cutters can be arranged to extend deeper into the material of the rack bar than do the broaching cutters which form the teeth at the ends of the rack bar or all of the tooth broaching cutters can be arranged to extend the same depth into the material of the rack bar and the cutters, other than those at the centre of the rack, may have their cutting edges extended (so that all the cutters have the same radius for convenience of manufacture).

For the avoidance of doubt the present invention is applicable to assemblies in which the axis of the pinion extends at 90° with respect to the rack bar axis or where the pinion axis is at an acute angle with respect to the rack bar axis.

Drawings

Embodiments of a power assisted steering gear assembly constructed in accordance with the present invention will now be described, by way of example only, with reference to the accompanying illustrative drawings, in which:

Figure 1 schematically illustrates a first embodiment of the assembly in which the rack bar is provided with a longitudinally recessed bearing surface by which the biasing force to maintain the rack and pinion in engagement is varied in accordance with the pitch of the rack teeth, and

Figure 2 schematically illustrates a second embodiment in which the rack bar has a substantially straight bearing surface and the height of the rack teeth is varied ot provide an effective variation in the biasing force in accordance with the variation in pitch of the rack teeth.

Detailed description of drawings

For convenience of description, the relative dimensions and profiles of the components illustrated have been greatly exaggerated.

In each of the embodiments the power assisted steering gear assembly has a rack bar 1 with a longitudinal axis 2 along which it is displaceable in a housing 3. The rack bar has a rack 4, the array of teeth in which have their crowns substantially coplanar and parallel to the axis 2. Mounted in the housing 3 is a cylindrical straight toothed pinion 5 which is rotatable about a pinion axis 6. The teeth of the pinion engage the rack teeth 4 in conventional manner and the pinion is rotated in response to a steering input, again in conventional manner to effect displacement of the rack bar 1 to provide a steering output. In a typical form of assembly the steering input to rotate the pinion 5 will adjust an hydraulic valve (not shown) which controls the flow of fluid t a s rv motor (such as a double acting piston and cylinder device, not shown) coupled to the rack bar 1 (or some ther conveni nt part f th steering output) to assist in displacement f the steering output in the direction intended by th steering input. Mounted in the housing 3 oppositely t th position of ngagement between the pini n 5 and rack 4 is a support such as a yok 7 which is

resiliently mounted at 8 relative to the housing 3 to be urged into sliding engagement with a smooth bearing surface 9 on the side of the rack bar 1 remote from the rack 4. The yoke 7 serves to bias the rack 4 into engagement with the pinion teeth.

The teeth in the rack 4 are provided with a variable pitch within the operative length of the rack, such a pitch variation conveniently being achieved in the manner discussed in U.K. Specification No. 977,434 so that the effective gear ratio between the pinion and rack will change over the operative length of the rack and symmetrically about the mid-point of the rack. More particularly, the rack teeth at the centre, or in the central region, of the operative length of the rack are provided with a smaller pitch than the rack teeth in each of the end regions of the rack.

In the embodiment of Figure 1 the rack 4 has a central tooth region 10 the teeth in which are of substantially constant pitch and end tooth regions 11 the teeth in which are also of a substantially constant pitch but which pitch is greater than the pitch of the teeth in the region 10. Provided between the teeth in the region 10 and in the respectively adjacent regions 11 are transition teeth 12, the teeth in which transition regions are of varying pitch and flank profile to provide a smooth transition in drive and gear ratio change as the pinion 5 moves between the teeth in the central region 10 and an adjacent end region 11. The rack teeth 4 in Figure 1 will have a pitch line 13 which is located nearer the crowns of the teeth in the region 10 and nearer to the roots of the teeth in the regions 11 so that the pitch circle diameter of the pinion 5 is greater when the pinion teeth engage the toothed region 11 than when the pinion teeth engage a toothed region 10. With this arrangement for power assisted steering a given angular displacement of the pinion 5 will result in a relatively small axial displacement of the rack 1 when the pinion engages the teeth 10 as compared with the displacement of the rack bar 1 which will result from a similar rotation of the pinion when it engages the teeth 11 - this is preferred to take advantage of the characteristics of the control valve for the servo motor so that the control valve will become operational to actuate the servo motor in response to a relatively small displacement of the rack bar 1.

Although the yoke 7 will urge the rack and pinion teeth into engagement it is found that with a straight toothed pinion and correspondingly profiled teeth in the rack, the appropriate biasing force on the yoke 7 to provide the required firmness of engagement between the pinion and the teeth of small pitch in the region 10 may be inadequate to provide the required firmness of engagement between the pinion teeth and the teeth of larger pitch in the regions 11 as the rack is displaced between the pinion and the yoke (so that a nois or rattle may develop detween the pinion t th and the teeth in a region 11 when in ngagement). To alleviat this problem in th embodiment of Figur 1 the bearing surface 9 is recessed longitudinally as indicated at *9a* so that as th rack bar 1 is displaced beneath th pinion from its mid-length position and t wards either of its ends, the yoke 7 slides v r th bearing surface *9a* and is displaced laterally against its resilient biasing 8 t increase the distance between the yoke and the pinion axis 6.

In this way the biasing force exerted by the yoke 7 will increase as the pinion moves into engagement with the teeth in an end region 11 to provide firm engagement between the meshing teeth. Although in Figure 1 the recessed bearing surface *9a* is shown concave as a smooth longitudinally extending curve it will be appreciated that this bearing surface may have one or more regions which are parallel to the rack bar axis 2 where each such region or regions is located oppositely to a region of the rack teeth which are of a substantially constant pitch. For example, in Figure 1 the bearing surface *9a* can have end regions opposite to the respective toothed regions 11 which are parallel to the axis 2, a central bearing region which is opposite to the toothed region 10 and which is also parallel to the axis 2 (but which central bearing region is stepped down from the bearing surface end regions) and transition bearing surface regions which are located oppositely to the toothed regions 12 and which provide the required change in biasing force as the yoke 7 slides over those transition bearing surface regions and as the pinion teeth move over the transition rack teeth 12. As previously mentioned the recess form of the bearing surface *9a* is shown greatly exaggerated and in a typically sized rack and pinion gear for a motor vehicle the depth of the recess (and resultant lateral displacement which is applied therefrom to the yoke 7 in the pinion moving between engagement with the minimum and maximum pitch rack teeth) will be in the order of 0.004 inches (0.1 millimetres).

In the embodiment of Figure 2 the rack teeth 4 may conveniently be regarded as having a constantly varying pitch over its operative length so that the gear ratio between the pinion and rack will change continuously during displacement of the rack bar 1. The main feature of Figure 2 however is that the bearing surface 9 is substantially parallel to the axis 2 of the rack bar and the required variation in biasing force as previously discussed to increase the lateral loading between the rack and pinion teeth as the pinion moves into engagement with rack teeth of increasing pitch) is provided by forming the rack teeth to laterally displace the pitch line 13 towards the plane in which the crowns of the rack teeth are located as the pitch of those rack teeth increases. As shown in Figure 2, this may be achieved by progressively decreasing the height of the rack teeth 4 which in this case is towards the end of the rack where the pitch of those teeth progressively increases. Unlike the pitch line 13 in Figure 1 which will have straight part lengths parallel to the axis 2 corresponding to the toothed regions 10 and 11 and dog leg part lengths corresponding to the transition tooth regions 12, the pitch lin 13 in Figure 2 may be substantially straight and parallel to th axis 2 or may follow a smooth shallow curv depending up n the uniform variation in the pitch of the teeth. By this arrangement in Figur 2 it will b apparent that as the pinion moves progr ssively into engagement with the rack teeth towards the end of the rack it will tend t increas its pitch circle diameter and provide

a lat ral reaction through the rack bar on to the yoke 7 to displace the rack bar and yoke laterally and increase the biasing force which urges the rack and pinion teeth in engagement.

For convenience of manufacture of the broaching cutters, the rack teeth in Figure 2 may be modified to be all of the same depth whereby the gaps between adjacent teeth are all of the same depth as shown by the broken lines 20 (consequently the involute form of the teeth is not changed as compared to the Figure 2 arrangement but the respective teeth are merely extended, as appropriate, to be of constant depth).

In each of the embodiments the pinion axis 6 may be at 90° or at an acute angle with respect to the rack bar axis 2. Furthermore, the rack teeth 4 can be formed by conventional broaching techniques with appropriately shaped broaching cutters. The recessed bearing surface *9a* can readily be machined or ground to the required depth and profile on what may otherwise be regarded as a conventionally shaped rack bar. The varying height teeth in the embodiment of Figure 2 can readily be machined using a longitudinal array of broaching cutters similar to those which would be employed for forming the teeth in the embodiment of Figure 1 but with the broaching cutters displaced laterally with respect to each other so that the broaching cutters become less proud as they approach each end of their longitudinal array from the centre of that array.

Although the rack bars are illustrated, for convenience, to be formed from cylindrical stock, it will be realised that the present invention is applicable to any cross sectional shape of rack bar such as triangular or T-section as are frequently employed provided that an appropriate bearing surface is provided. It will also be realised that the support is not necessarily in the form of a yoke and may have more than one support part engaging with an appropriate bearing surface part.

CLAIMS

1. A power assisted steering gear assembly comprising a rack bar having a longitudinal axis along which it is displaceable in the housing; a rack on the rack bar, the crowns for the teeth of which are substantially coplanar and parallel to the longitudinal axis; a straight toothed pinion rotatably mounted in the housing with its teeth engaging the rack, said pinion being rotatable in response to a steering input to effect in displacement of the rack bar and provide a steering output; servo motor means associated with said steering output; control means responsive to said steering input and controlling said servo motor means to that the latter provides power assistance for the steering output; support means m unt d in th h using oppositely to the positi n of engagement betwe n th rack and pinion, said support means engaging a sm oth bearing surface n the side of the rack bar remote from the rack to resiliently bias the rack int engagement with th pinion; said rack having teeth which, with respect to the pinion teeth, vary in pitch along a pitch lin of th rack whereby th rack and pinion provide a gear ratio that varies during said displacem nt of the rack bar, the rack having a c ntral tooth region the pitch f the te th in which is less than the pitch of teeth in each end r gion f the rack, and wherein said pitch line and bearing surface are profiled with respect to each other over the longitudinal extent of the rack so that the biasing force exerted by the support means on the bearing surface to urge the rack into engagement with the pinion is greater when the pinion engages with the rack teeth of relatively larger pitch than it is when the pinion engages with the rack teeth of relatively smaller pitch.

2. An assembly as claimed in claim 1 in which the bearing surface is recessed over its longitudinal extent so that the support means is displaced laterally away from the axis of rotation of the pinion as the rack moves longitudinally into a position where its larger pitch teeth engage with the pinion to increase the biasing force provided by the support means.

3. An assembly as claimed in claim 2 in which the longitudinal recess in the bearing surface is formed by grinding or honing.

4. An assembly as claimed in claim 1 in which the effective height of the rack teeth varies over the rack to provide a variation in profile of the pitch line of the rack relative to the bearing surface and cause lateral displacement of the rack bar and of the support means against its resilient biasing to increase the biasing force as the pinion moves into engagement with larger pitch rack teeth.

5. An assembly as claimed in claim 4 in which the bearing surface is substantially straight and parallel to the longitudinal axis of the rack bar.

6. An assembly as claimed in any one of the preceding claims in which the support means is displaced laterally against its resilient biasing substantially 0.003 to 0.005 inches during displacement of the rack from engagement of the pinion with the minimum pitch rack teeth to engagement of the pinion with the maximum pitch rack teeth.

7. An assembly as claimed in any one of the preceding claims in which the final form of the teeth in the rack is achieved by broaching.

8. An assembly substantially as herein described with reference to Figure 1 of the accompanying illustrative drawings.

9. An assembly substantially as herein described with reference to Figure 2 of the accompanying illustrative drawings.

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